MicroSD Operational Experience and Fault Mitigation Techniques

Joshua Lamorie
Francesco Ricci

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  - Control (e.g. flight, instrument, motor, …)
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- Some goals:
  - Robust
  - Affordable
  - Low power, small size
  - Fast application memory
  - Computationally capable
  - Accommodate (almost) arbitrary interfaces
  - Familiar S/W development and runtime environments (e.g. Linux, Yocto)

Background

- To achieve these goals Xiphos cards feature:
  - General purpose CPUs and programmable logic
  - Low power RAM
  - NOR flash to store application configuration (bootloaders, kernel, rootfs, logic bitstream)
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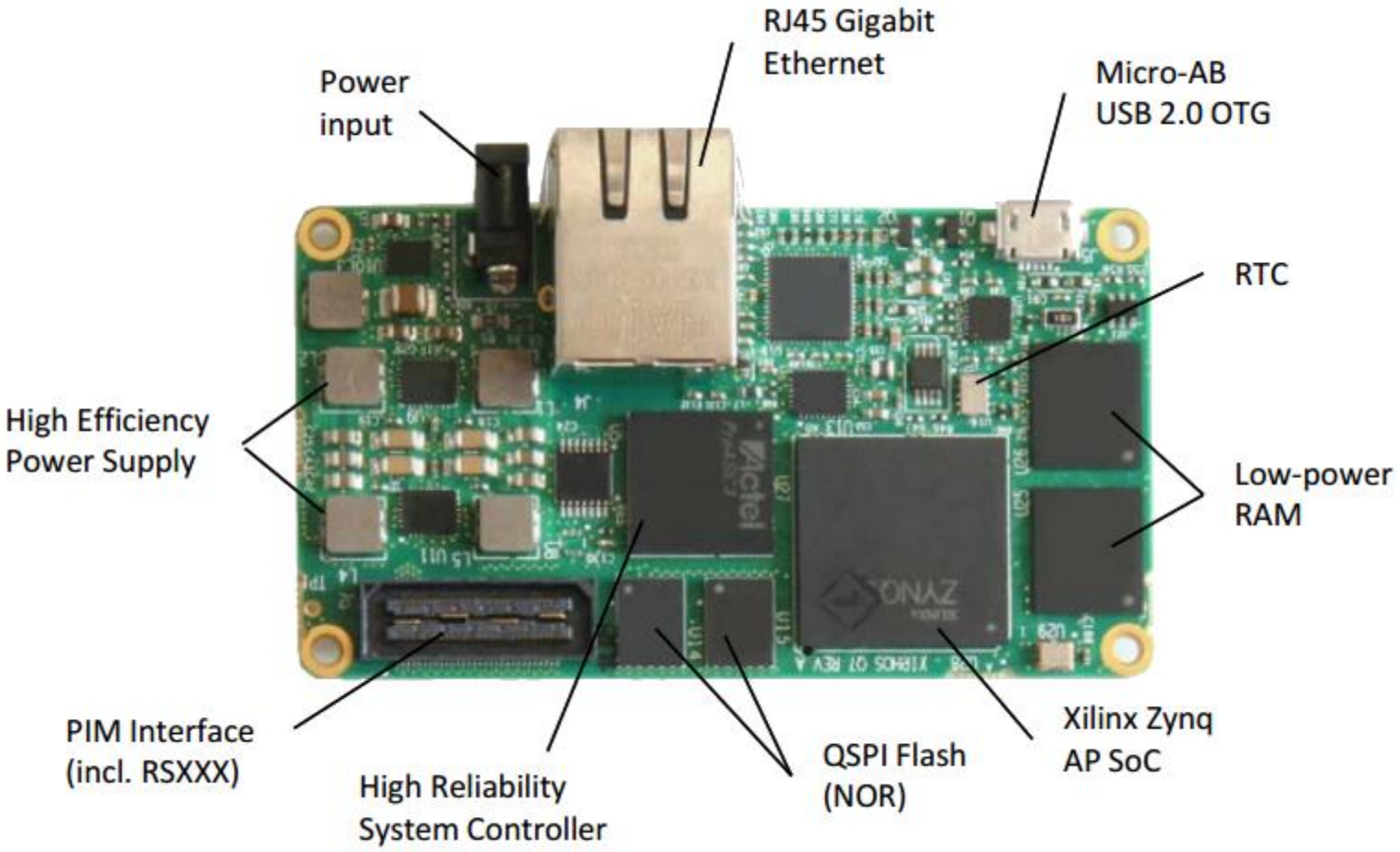
- Example: Q7 processor card (2014)
  - Xilinx Zynq-7020 (2 x ARM Cortex-A9, Artix-7 FPGA)
  - 1 x 512 MB and 1 x 256 MB LPDDR2 RAM, 2 x 32 GB MicroSD

Q7 Top



Q7 Bottom

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  - Controllers that implement error correction and wear leveling
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- These mitigations are appropriate for the terrestrial, COTS use-case but additional errors occur in space
  - Core NAND flash components?
  - FTL controller?
  - FTL controller configuration memory?

Xiphos Experience

In Orbit Observations

- Xiphos has supplied spacecraft developers with (Micro)SD equipped processors for LEO applications since 2006. Examples:
  - Cameras systems for SpaceQuest and Bigelow Aerospace Genesis-1/2
  - AIS payload processors for SpaceQuest
  - Payload monitoring and networking for the OSTEO-4 experiment on ISS
- Failures are rare but do occur
- Symptom: card information and status register queries result in responses but corrupted values
- Vendor feedback: controller firmware corruption resulting in device factory reset
- Perfect correlation: a rise in power consumption of ~100 mA @ 3.3 V
- This rise is about twice the expected peak current during SD write operations but much lower than the threshold required to trip standard latch-up protection
- This is a condition known as “low-current latch-up”

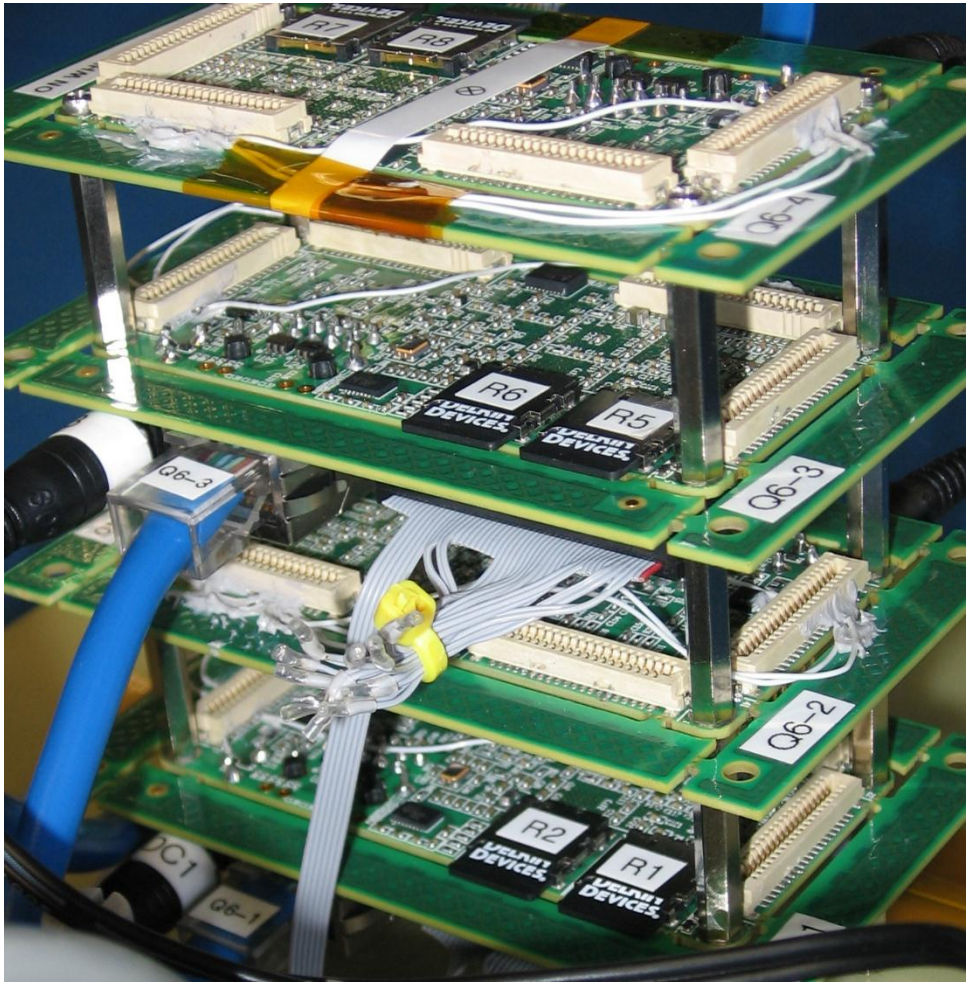
Xiphos Experience

Radiation Test Observations

- Xiphos tested (Micro)SD cards and Xiphos processor cards against the Proton Irradiation Facility (PIF) at TRIUMF in 2004, 2011, 2012, 2014
- Test goals:
  - Detect weaknesses in Xiphos designs
  - Characterise the radiation events that produce SD card failures
  - Characterise the SD card failures themselves
- Observed failures:
  - Temporary, transient write errors (low-current latch-up)
  - Temporary, multi-sector data corruption (low-current latch-up)
  - Destruction (one observation) (30 krad TID)
- Radiation:
  - Transient errors can occur at relatively low doses e.g. 2 – 5 krad
  - One campaign actively sought to find some “sweet spots” e.g. errors occur within 100 s under a 63 MeV bean at 6 nA

Xiphos Experience

Radiation Tests



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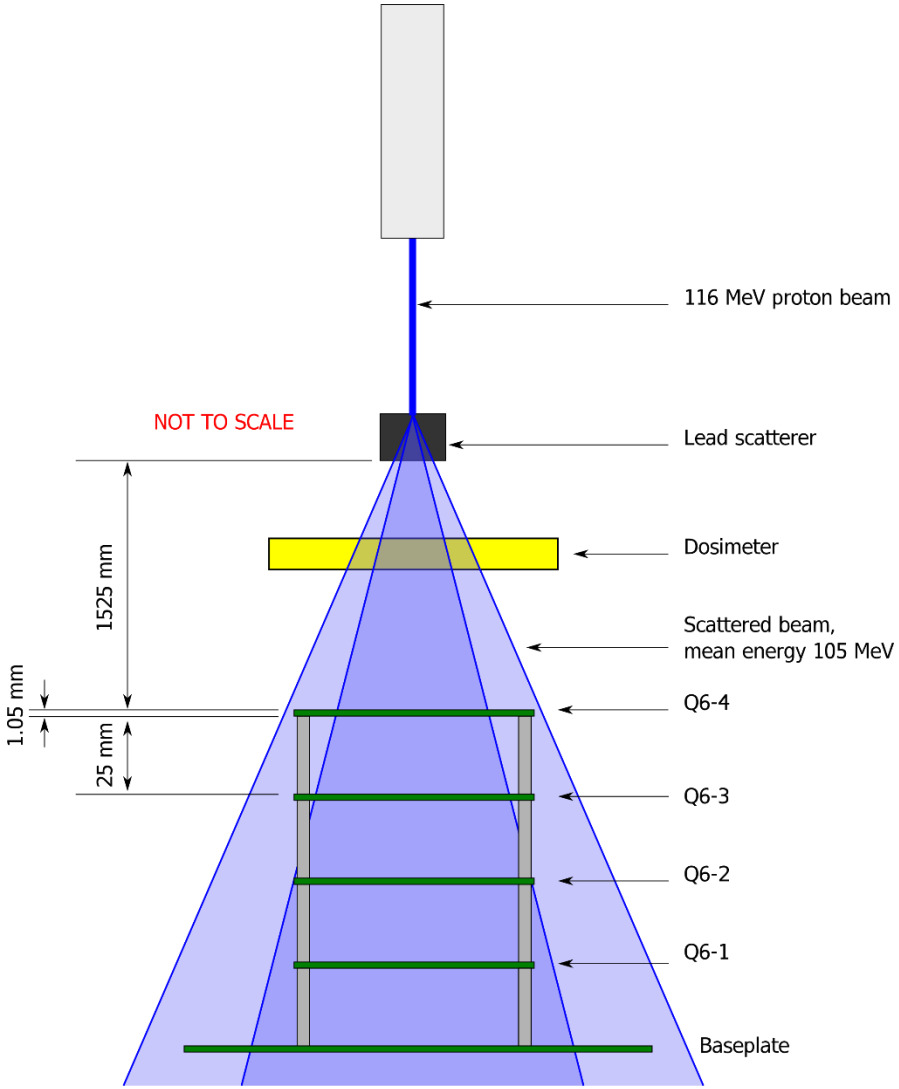

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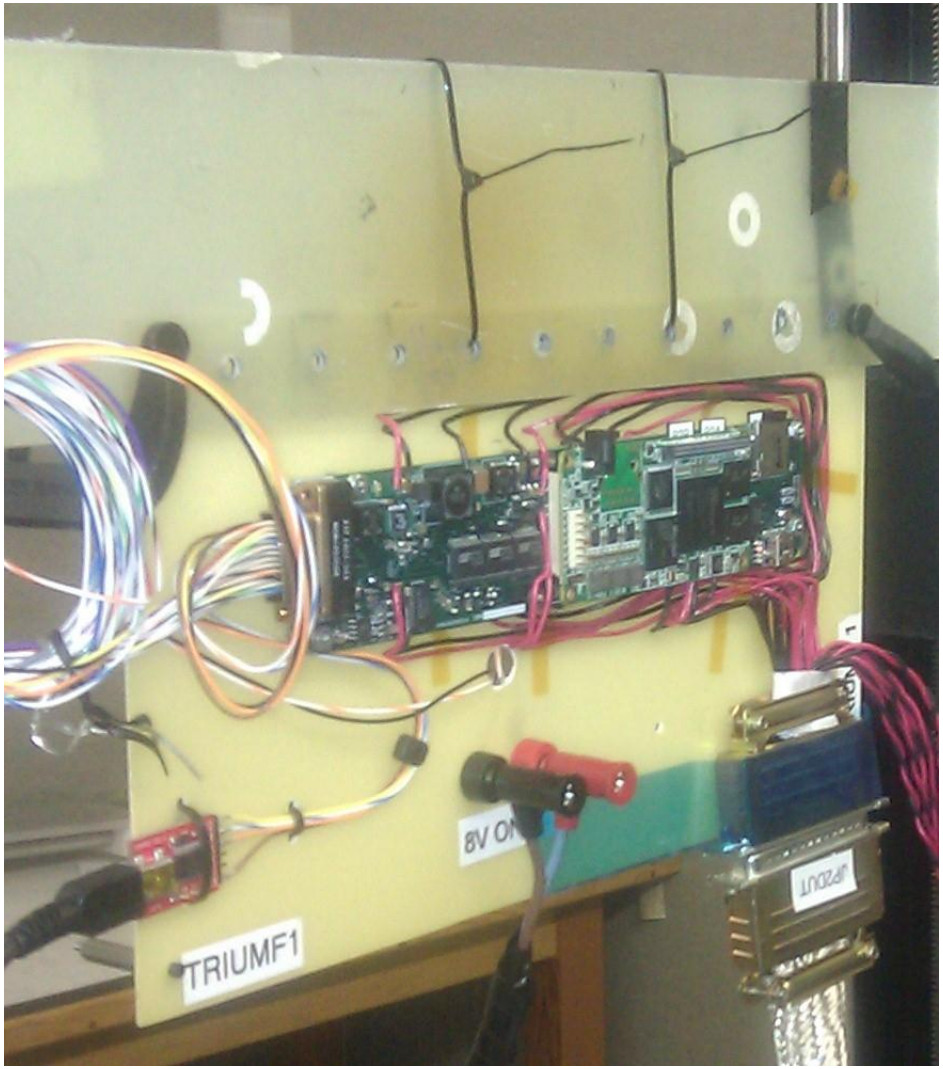

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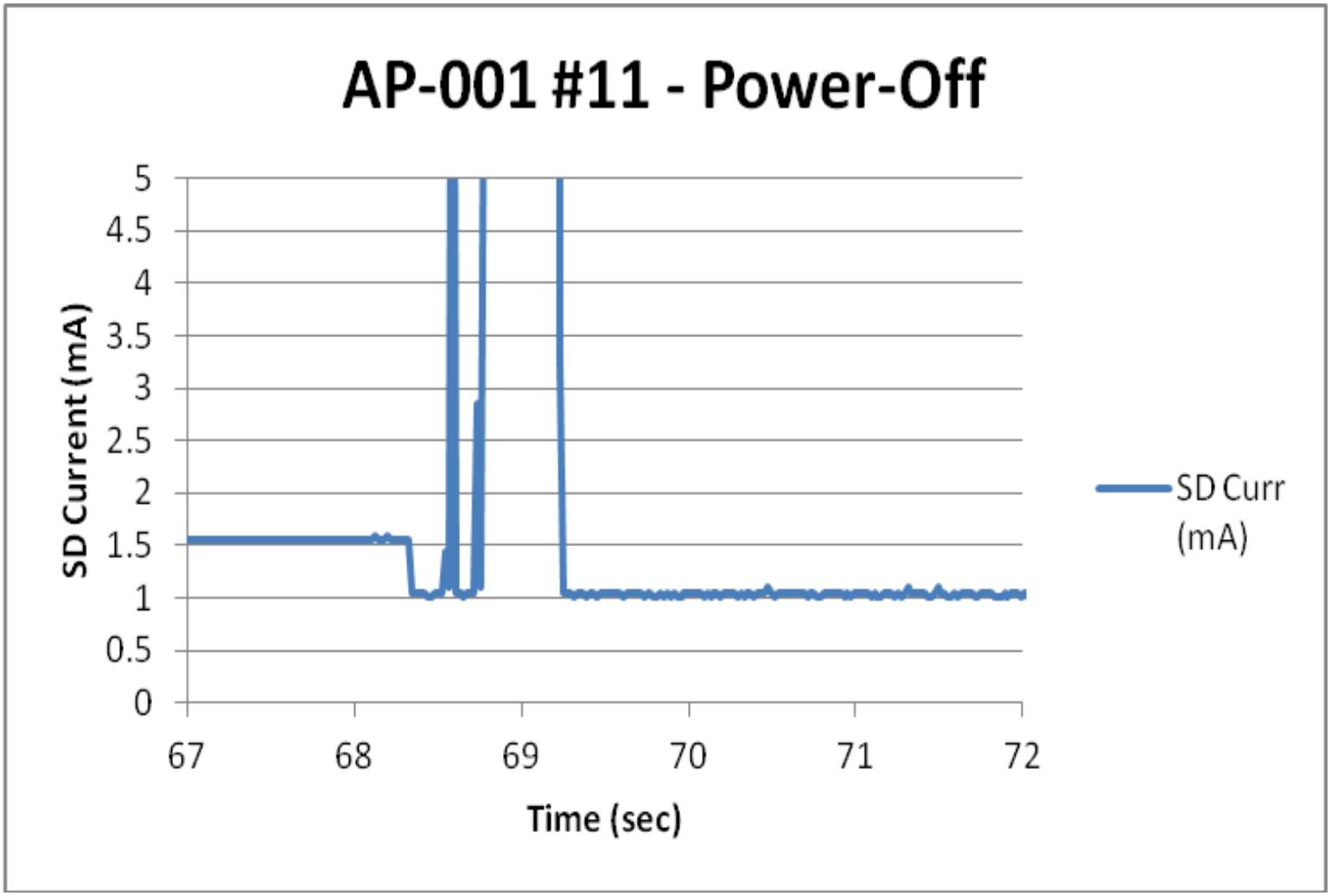
- Low-current latch-up detection:
  - ProASIC3 monitors MicroSD card power consumption
  - Automatic shutdown is triggered when the overcurrent condition is detected
  - Reaction time is < 1 microsecond
  - Extremely effective according to the 2014 TRIUMF test campaign

Xiphos Experience

Low-Current Latch-Up Detection



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- Robust design!
  - Store critical firmware and software in redundant, error corrected NOR flash
  - Store payload data to redundant MicroSD cards
  - Keep MicroSD cards unpowered when not in use

Summary

- Xiphos…
  - Has flown SD and MicroSD cards for almost 10 years
  - Observed SD card failures in orbit
  - Tested SD cards at TRIUMF since 2004
  - Designed techniques to protect SD card data from radiation upsets
    - Low-current latch-up detection
    - Software-based robust storage mechanism for corrupted sector detection and repair
    - FTL controller firmware reconfiguration (in progress)
  - Tested low-current latch-up detection and software-based robust storage
- Xiphos is confident that event detection techniques and robust design elements can permit long term and reliable use of MicroSD cards in orbit

Contact

- For more information, please contact:

Stephane Germain
Xiphos Technologies
Tel: 514-847-9474 x205
Cell: 514-573-9127
Email: stephane.germain@xiphos.com

- Or visit www.xiphos.com